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DETECTION OF VOIDS AND INHOMOGENEITIES IN FIBER GLASS REINFORCED PLASTICS BY MICROWAVE AND BETA-RAY BACKSCATTER TECHNIQUES

Technical Report

K. A. Fowler
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Date 20 May 1966

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DETECTION OF VOIDS AND INHOMOGENEITIES IN FIBER GLASS REINFORCED PLASTICS BY MICROWAVE AND BETA-RAY BACKSCATTER TECHNIQUES

Technical Report

K. A. Fowler
H. P. Hatch

DA PROJECT TITLE: Application of Microwave and Beta-Ray Backscatter In Nondestructive Testing of Plastic Items

DA PROJECT NO: AW-5-15221-01-AW-M6

ABSTRACT

Microwaves were used as a means of detecting voids and inhomogeneities in fiber glass reinforced plastics. A number of experiments that were designed to empirically establish the limits of detectability of various types of defects are described. Based on the results of the investigation, it is possible to detect a 1/8-inch-diameter hole in a 1/4-inch-thick panel of fiber glass reinforced plastic with X-band microwaves. However, several factors such as sensitivity of the signal amplitude to defect location, test-piece position, geometry, and homogeneity make interpretation of results difficult. Beta-ray backscatter measurements are potentially useful as a means of detecting local variations in glass-to-resin ratio. The contribution of fillers as a third constituent in the composite system must, however, be considered in establishing a relation between back-scattering and glass-to-resin ratios.

CONTENTS

SUBJECT

Nondestructive examination of fiber glass reinforced plastics for voids and inhomogenieties.

OBJECTIVES

To determine the feasibility of detecting recognized defects in fiber glass reinforced plastics through the use of microwave and beta-ray backscatter methods, and to establish detectability limits of defects under various conditions. A further objective was to evaluate one of the commercial, microwave nondestructive test instruments which is shown in Figure 1.

CONCLUSIONS

1. X-band microwaves (9.4 gHz) can be utilized to detect voids and inhomogeneities in glass-reinforced plastic (GRP) panels.

2. Sensitivity to hole-type defects in GRP is improved by incorporation of a metallic-reflecting surface placed in back of the sample.

3. The position of a flat reflector for maximum defect signal is approximately 0.2 λ for section thicknesses less than 0.2 λ, and immediately in back of the panel for section thicknesses equal to or greater than 0.2 λ.

4. With a one-inch square microwave horn, a reflector size of 1-1/2 inches square or larger should be used for maximum defect signal.

5. A circular aperture placed over the one-inch horn is effective in producing defect signals of greater amplitude over a limited range of thickness.

6. Under certain conditions it appears possible to detect 1/8-inch diameter holes in 1/4-inch-thick GRP, but this depends strongly on the homogeneity of the material.

7. In general, it was not possible to differentiate between random signals from material variability and defect signals by means of phase-angle measurements.

8. The dipole probe supplied with the microwave test instrument provides excellent sensitivity to surface and near-surface defects but appears to be limited to detecting voids within 0.05-inch of the surface.

CONCLUSIONS (Continued)

9. Beta-ray backscatter appears to offer a potential means of determining resin-to-glass ratio. However, the contribution of fillers as a third constituent in the composite system on the beta-ray backscatter versus resin-to-glass ratio relationship must be known.

10. The results of the microwave portion of the investigation indicate that application of this general method to a component of varying contour, such as a gunstock, will be a difficult and complex procedure.

RECOMMENDATIONS

1. A reappraisal of the nondestructive testing requirements for adequate quality assurance of GRP gunstocks should be conducted in consideration of recent developments.

2. If it is determined that a nondestructive test requirement still exists, then a concentrated effort should be made, involving designers, and plastics and nondestructive test engineers, to define realistic goals and approaches, taking into account practical limitations in each of the above areas.

3. If the microwave approach is continued, consideration should be given to higher frequencies where scattering from smaller voids and inhomogeneities becomes more significant and focusing of the energy by appropriate lenses is feasible.

1. BACKGROUND

An interest in developing the capability and techniques of nondestructively evaluating fiber glass reinforced plastics (GRP) originated with the anticipated need for inspecting GRP gunstocks for the M14 rifle and M79 grenade launcher in particular, and future plastic stocks and smaller parts in general.

Although an extensive list of unacceptable defects has been prepared,[1] there has been no generally accepted determination made regarding either the relative importance of each of the many types of material and processing defects or the tolerance limits considered to be acceptable. This situation is due, in part, to the lack of adequate data upon which sound judgments on these matters can be based. Service failures of preproduction samples have been rather limited and analysis of such failures has, in general, been lacking. The cataloging of failures by type and frequency has not been practiced. Therefore, little information is available from service experience.

Recent tests on sample M14 stocks have demonstrated that the GRP stock has two to three times greater energy absorbing capability and strength than the wood stock it is designed to replace. With this great a safety factor, the margin for error is considerable. Understandably, the earlier sense of urgency and interest in a nondestructive test procedure has somewhat waned.

During the period of maximum interest in the development of nondestructive test procedures for GRP stocks, the Nondestructive Testing Section at Springfield Armory initiated an investigation to determine the feasibility of eventually examining stocks by microwave and beta-ray back-scattering techniques. Since, at the time of equipment purchase, the most important defect types and tolerance limits had not been established, it was considered advisable to obtain equipment of the greatest potential application and flexibility until such time as the specific goals were defined. Therefore, a commercially available X-band (9.4 g H_z) nondestructive testing system was procured for the microwave portion of the investigation, and a commercial, beta-ray backscatter, plating-thickness gage was obtained to evaluate the applicability of this technique.

After a number of discussions, it was quite arbitrarily established that a 1/8-inch diameter hole in the pistol-grip area of the stock would constitute the maximum allowable defect of this type. Resin-rich and/or resin-starved areas were also considered to be detrimental, but no limits have been established for this type of defect. A third defect category which is of concern, but is not amenable to inspection by

1. BACKGROUND - Continued

either of the methods discussed herein, is failure of the glue line along which the two halves of the stock are bonded.

On this basis, investigators proceeded to ascertain if (a) the microwave technique could be used to adequately determine the presence and location of voids of 1/8 of an inch in diameter or larger in GRP thicknesses of 1/2 inch or less, and (b) if the beta-ray method could be used to monitor variations in glass-to-resin ratios.

2. INTRODUCTION

The utilization of GRP products in critical aerospace structural components has stimulated a growing interest in the development of reliable nondestructive test procedures for the inspection of this material for defects. Possibly the most notable example of this trend is the development of the filament-wound, Polaris rocket motor case - a component that, because of its cost and performance requirements, demands rigid inspection procedures. In response to the need for a nondestructive test system, a nationally known manufacturer of nondestructive test instrumentation developed a "CEBM" (corona, eddy current beta-ray backscatter and microwave) system. This system utilizes two of the methods selected for potential application to the problem of examining GRP gunstocks.

The literature documents a number of attempts to utilize microwaves for the nondestructive inspection of dielectric materials, which have met with varying degrees of success. Numerous claims regarding the potential application of microwave techniques to this problem have also been made.

A brief account of the development of the microwave test for the Polaris motor case[2] indicates that voids on the order of 2mm in diameter by 1/2-inch long and delaminations are detectable by using a reflector in back of a test panel at a test frequency of 17 g H_z. In another investigation, an unsuccessful attempt was made to evaluate per cent porosity in the range of 0.6 per cent to 2.0 per cent in orthogonal filament-wound panels by means of free-space dielectric constant measurements, and by using microwave interferometer techniques at 12 g H_z.[3] Rockowitz and McGuire, on the other hand, have reported on a system for detecting voids in honeycombed ablative material.[4] They were successful in detecting holes 1/4-inch in diameter by 1/8-inch high in 2-inch thick honeycomb, utilizing scattering effects at 69 g Hz. Prine[5] has shown detection of voids 2mm in diameter and 1/4 of an inch in length in GRP panels 5/8 of an inch thick, using the interferometer principle at a test frequency of 10.5 g Hz. Other literature relating to the application of microwaves to the nondestructive test of nonmetals is listed in the Bibliography (Appendix B)[6,7,8]

2. INTRODUCTION - Continued

The application of beta-ray backscatter to determine glass-to-resin ratios in GRP products is based on the difference in the effective atomic numbers of the resin and the glass and has been well documented.[9,10]

The atomic number of the glass is 9 - 10, whereas that of the epoxy resin is about 4. Penetration of the beta rays is approximately 0.040 of an inch using a strontium - yttrium - 90 source (2.18 Mev maximum beta energy). Therefore, thickness variations in sections thicker than 0.04 inch do not affect the results of the test.

3. PROCEDURE

a. Samples

As mentioned earlier, it was determined that a 1/8-inch diameter hole in a GRP section thickness of 1/2 inch to 1/4 inch would constitute an unacceptable defect. To determine the detectability of holes by microwave methods, six-inch by six-inch panels of commercially prepared GRP panels were cut and holes of 1/4-inch, 1/8-inch and 1/16-inch diameter were drilled through the panel at the center, and normal to the panel surface, to represent defects. Panel thicknesses in the range of 1/16 inch to 1/2 inch were used.

In order to evaluate the sensitivity of the microwave method - to holes of depths less than the total thickness of the panel - flat-bottom holes of 1/4 inch, 1/8 inch and 3/32 inch in diameter were drilled in 1/4-inch-thick panels to depth increments equivalent to 10 per cent of the panel thickness or 0.025 inch. The limit of detectability of this type of artificial defect was then established with the side containing the defect facing toward and away from the source of microwave energy.

Attempts to produce completely internal cavities were abandoned early in the investigation for two reasons: (1) The panels produced were not as uniform as commercially prepared panels, and (2) The holes were difficult to make and control.

To evaluate the beta-ray backscatter method of detecting local variations in glass-to-resin ratio, samples four inches wide by six inches long were prepared by molding three layers of pre-impregnated fiber glass mat to produce a sample thickness of about 1/16 of an inch. To simulate resin-rich areas, holes were cut in the middle layer of mat. When the three layers were molded, the resin from the surrounding material flowed into the area of the hole. This replaced the glass in that area and produced a resin enrichment.

3. PROCEDURE - Continued

This method of simulating resin-rich areas was based on experience with stocks fabricated by layup techniques, using pre-impregnated mats. It had been observed that, occasionally, one layer of mat was undercut or folded, leaving a weakened resin-rich area. This particular type of defect will probably not be as potentially serious because the stocks made in the future will be of molding compound.

b. Microwave Tests

Two basic approaches to the problem of small void detection in nonmetallics by microwave methods were considered for use with the system shown in Figure 1. The first approach was to measure differences in reflected energy by means of phase and amplitude variations in the standing wave pattern. To obtain the greatest effect from the void, the microwave energy should be concentrated in the vicinity of the defect. This general method will be referred to hereafter as the reflection method.

The second possible means of detecting voids with microwaves was by a scattering of the energy from the void. Rockowitz and McGuire have stated that significant scattering effects can be obtained when

$$\frac{2\pi}{\lambda} a \approx 1$$

where a is the minimum radius of void and λ is the wave length of the incident radiation.(4) For a test frequency of 10 g H_z, the wave length is 3 cm and the radius of the minimum size of void would be on the order of 0.5 cm. The minimum detectable hole would, therefore, be approximately 1 cm or 0.4 inch in diameter. A hole 1/2 inch in diameter in a cube of plastic 18 inches by 18 inches by 18 inches has been detected using this principle and the same test instrument used in this investigation.(11) Since the minimum hole size that must be detected in the GRP gunstock is 1/8 inch in diameter, the scattering technique appears to be precluded at this test frequency. It is worth re-emphasizing that the minimum size of single void detectable by Rockowitz and McGuire, working at a test frequency of 69 g H_z and utilizing the scattering method, was 1/4 inch in diameter by 1/8 inch high in two-inch-thick material. Therefore, it is probable that a frequency in this range would be required to increase the scattering cross-section of a 1/8-inch diameter void to a sufficient value to produce significant scattering. On the basis of the preceding considerations, the scattering approach was discarded in favor of the reflection technique.

3. PROCEDURE - Continued

Preliminary measurements made by simply supporting the sample panel over the end of a one-inch square horn, as shown in Figure 2 (but without the reflector shown), revealed a completely inadequate sensitivity to holes drilled through the sample. By increasing the system sensitivity, the holes did produce a defect indication but the "background" due to variations within the sample itself and minor variations in positioning, made unequivocal identification of the holes difficult. These measurements were made by first "balancing" the wave guide by means of the slide-screw tuner to cancel the reflections from the load which, in this case, was the defect-free portion of the sample being tested. This condition results in zero-reflected signal and both SWR (standing wave ratio) meters and the x-y chart recorder indicate zero signal (see Figure 1). The sample panel was then moved so that the hole was directly over the center-axis of the wave guide. The change in the standing-wave pattern was then monitored by means of the SWR meters or the x-y recorder. The detector of the system is designed to give an output related to the in-phase and quadrature components of the standing wave. Presentation of the detector output on the x-y recorder, therefore, permits direct readout of the phase as well as the resultant amplitude of the change in reflected signal. The SWR meters monitor the in-phase and quadrature components of the standing wave only, and phase angles as well as resultant amplitudes must be calculated.

Because of the poor sensitivity to artificial defects in the form of holes observed with the simple reflection technique, a method was sought of improving sensitivity by concentrating the energy of the microwave beam more completely in the vicinity of the defect. It was noted earlier that in the microwave work associated with the development of the CEBM Polaris inspection system, Hendron, et al.[2] used a metallic reflector in back of the GRP under test. Although not specifically stated in their report, it was assumed that the effect of the reflector was to concentrate the interaction of the field with the material more locally in the vicinity of the defect, thereby increasing sensitivity. Flat metallic reflectors were made to various sizes in the range of 1/4 inch to three inches square. The effect of reflector size and position was then examined. A typical setup used in this phase of the work is shown in Figure 2. The basic measurement procedure was the same as that described earlier without a reflector. More recently it was found that the amplitude of the signal from a defect can also be increased by covering the end of the 1-inch horn with a metal sheet containing an aperture approximately equal to $\frac{\lambda}{2}$.

3. PROCEDURE - Continued

A second method of confining the microwave field to a small area was by means of a coaxial dipole termination. Such a "dipole probe" was supplied with the microwave instrument used in this investigation. Figure 3 illustrates the use of the dipole probe to detect voids in GRP panels. The probe itself is 1/8 of an inch in diameter. The same method was used to monitor differences in reflected energy.

To summarize, the following factors were considered in the microwave portion of the work:

(1) Sensitivity to through-holes drilled normal to the surface of GRP panels.

(2) Effect of reflector position on sensitivity.

(3) Effect of reflector size on sensitivity.

(4) Effect of panel position on sensitivity.

(5) Relative sensitivity to defects as measured with a one-inch horn and dipole probe.

(6) The effect of aperture of the one-inch horn on sensitivity.

(7) Sensitivity to blind holes of various depths on GRP panels.

c. Beta-Ray Backscattering Tests.

Figure 4 shows the beta-ray backscatter test instrument obtained to determine the feasibility of detecting local variations in glass-to-resin ratios in GRP. The sample panel was positioned above the source cup. Backscattered electrons incident on the window of the G-M tube were counted for a fixed period of time. The two sources which gave the best results on the samples tested were 0.77 Mev thallium 204 and the 1.17 Mev radium D + E.

The instrument comes with a number of platens which are used to adjust the viewing aperture of the beta-ray beam. Measurements were made using the 1/4-inch diameter platen and a counting time of 30 seconds. The effect of distance between the source and sample was not investigated. Differences in the backscatter rate between the area of the sample having three layers of mat and that having only two layers were of primary interest.

4. RESULTS AND DISCUSSION

a. Microwave Tests

An initial attempt to detect a 1/4-inch-diameter hole in a 1/4-inch-thick GRP by reflection methods, using the one-inch horn without a metallic backing, resulted in poor sensitivity. Figure 5 illustrates the defect signal obtained from the 1/4-inch-diameter hole relative to the "background" variability of the sample. The effect of separation between the panel and the end of the one-inch horn is also indicated over the range of 0 to 1/4-inch separation. Both the defect signal and the background diminish with increasing separation between the horn and sample, but the defect signal remained approximately three times the background. A 1/8-inch-diameter hole was only marginally detectable.

This poor defect sensitivity was found to be improved by placing a flat, metallic, reflecting surface in back of the panel. The first factor considered was that of the position of the reflector relative to the sample with the sample touching the horn. Figure 6 shows the effect of reflector lift-off from the end of the one-inch horn on the defect signal produced by a 1/4-inch-diameter hole drilled through a 1/16-inch-thick GRP panel. It should be noted that the distance between the end of the horn and the reflector is expressed as a fraction of the microwave wave length, λ. The defect signals from a 1/4-inch-diameter hole in 0.18-inch, 0.25-inch and 0.50-inch-thick panels versus reflector lift-off are shown in Figure 7.

It was found that when the thickness of the panel was less than 0.2λ, the amplitude of the defect signal versus reflector lift-off curve either reached a maximum or went through an inflection at approximately 0.2 reflector lift-off above the end of the horn. For panels of thicknesses 0.2λ or greater, the amplitude of the defect signal falls uniformly with increasing reflector lift-off to a low value. For all samples except the 1/16-inch-thick panel, the maximum defect signal amplitude was obtained with the reflector touching the panel.

The effect of reflector size on the defect signal obtained from a 1/4-inch-diameter hole in 1/4-inch-thick GRP panel was determined. Figure 8 illustrates the effect of the size of square, flat reflectors on the curve of defect signal versus reflector lift-off above the horn. The 2-inch and 1-1/2-inch-square reflectors give approximately the same result. A reduction of the size to one-inch

4. RESULTS AND DISCUSSION - Continued

or 1/2-inch square produces a decrease in maximum defect signal and a slower rate of decline of defect signal with increasing reflector lift-off. To avoid the effect of reflector size, a 1-1/2-inch-square reflector or larger should be used.

Finally, the influence of panel position relative to the end of the horn was considered. The results of these measurements are summarized in Figure 9. This shows the defect signal from a 1/4-inch-diameter hole in a 1/4-inch-thick GRP panel versus reflector lift-off above the end of the horn for increasing separation between the horn and panel. The maximum defect signal is still obtained when the reflector is touching the back of the panel, but the amplitude of the maximum diminishes with increasing separation. At a separation of 0.05 inch to 0.10 inch, the defect signal drops to about 20 mv at a reflector lift-off of 0.4λ and is then insensitive to reflector lift-off over a limited range.

On the basis of the preceding findings, it was decided that further measurements, designed to establish the detectability limit of hole-type defects, would be made with a 1-1/2-inch-square reflector touching the back of the sample panel with the panel touching the horn. Figure 10 is a presentation of representative data showing the defect signal from 1/4-inch, 1/8-inch and 1/16-inch-diameter holes drilled through the center of panels 0.18 inch, 0.25 inch and 0.5 inch thick. With the reflector positioned to give maximum sensitivity, the 1/8-inch-diameter hole was only marginally detectable in the 0.06-inch-thick panel and is not shown. In all panels in the range of 0.18 inch to 0.50 inch in thickness, the 1/4-inch and 1/8-inch-diameter holes were detectable. The 1/16-inch-diameter hole is marginally detectable in the 0.18-inch and 0.25-inch-thick panels but was not detectable in the 0.50-inch-thick material.

It should be noted that the detectability of hole-type defects in GRP is strongly dependent on the material variability which produces random signals referred to as "Background" in Figure 10. The 0.25-inch-thick material was relatively uniform and the 1/16-inch-diameter hole was detected, whereas, inhomogeneities of the 0.50-inch-thick GRP lead to a higher background and the 1/16-inch-diameter hole was not detected.

Figure 11 shows the defect signals from holes in two types of 1/4 inch GRP. Type 1 is relatively uniform and the 1/16-inch-diameter hole is detectable. In Type 2, the greater variability of the material makes it impossible to detect the 1/16-inch-diameter hole. This again illustrates the dependence of defect detectability on the homogeneity of the sample.

4. RESULTS AND DISCUSSION - Continued

By using the dipole probe, as illustrated in Figure 3, the sensitivity to holes in various thicknesses of GRP panels was determined. The results of these measurements are shown in Figure 12. When compared with Figure 10, the curves of Figure 12 are quite similar, with one or two exceptions. The sensitivity to hole in the 1/16-inch-thick panel is improved, by using the dipole probe, to the point that a 1/8-inch-diameter hole can be detected. The "background" level also appeared lower in relation to the signal from holes in the 1/2-inch-thick panel. On the other hand, the relative background was somewhat higher in the 0.18-inch-thick panel, making detection of the 1/8-inch hole marginal. However, this material had the greatest lack of homogeneity.

The final method considered as a means of increasing sensitivity to holes in GRP was that of an aperture placed over the end of the one-inch horn. The results of these measurements are shown in Figure 13. The addition of an aperture significantly improved the sensitivity to holes in the 0.18-inch-thick GRP panel. These measurements were made using a 1/2-inch-square reflector rather than the usual 1-1/2-inch size. This resulted in a reduction of the random "background" signals obtained in the 0.18-inch-thick panels as compared with Figure 10. The aperture was not effective in increasing sensitivity to holes in 1/2-inch-thick panels; in fact, a considerable reduction in sensitivity was observed. Although the aperture offers some improvement for section thicknesses in a limited range around 0.2 of an inch, this improvement is not realized at the significantly greater panel thickness.

The detectability of defects in the form of flat-bottomed blind holes in 1/4-inch-thick GRP panels was the subject of the final phase of the microwave investigation. These holes were intended to simulate hidden defects within the material. The defect signal produced by the defect was measured with the face containing the defect toward and away from the source of microwave energy. When using the dipole probe, holes 1/4 of an inch, 1/8 of an inch, and 3/32 of an inch in diameter by 0.025-inch deep were detected when toward the probe. However, when in the face of the panel away from the probe, holes 1/4-inch by 0.10-inch deep could not be detected; this is due primarily to the relatively large field gradient outward from the probe tip. The defect signal obtained for a 1/4-inch diameter by 0.05-inch-deep hole facing the probe was equivalent to the signal obtained for a 1/4-inch hole drilled completely through the sample. On this basis, the dipole probe supplied with the microwave unit must be considered to be sensitive to holes less than 0.05 inch below the surface of the GRP. This depth limitation is not an inherent property of the dipole probe. Probes can be obtained with less-restricted field patterns.[12]

4. RESULTS AND DISCUSSION - Continued

If the one-inch horn is employed, 1/4-inch and 1/8-inch diameter by 0.10-inch-deep holes can be detected when toward the horn but, as shown in Figure 14, only the 1/4-inch-diameter by 0.10-inch-deep hole can be detected away from the horn. In contrast, if a 9/16-inch aperture is placed over the end of the horn, a significant gain in sensitivity is achieved, as illustrated in Figure 15. Under these conditions, a 1/8-inch-diameter by 0.10-inch-deep hole can be detected even when in the face that is away from the horn. Therefore, by utilizing this particular setup it does appear possible to detect 1/8-inch-diameter holes in GRP panels of [illegible]-inch thickness, provided the homogeneity is reasonably good.

b. <u>Beta-Ray Backscatter Test</u>

Figure 16 represents the results of very limited measurements of the beta-ray backscattering characteristics of GRP panels containing resin-rich areas prepared as outlined under "3. Procedure". The feasibility of the method is demonstrated, but improvements are believed possible. Shown in Figure 16 is a curve representing the average backscattered beta count as a function of the number of layers of 1-1/2-ounce preimpregnated mat in a 0.07-inch-thick panel. Also shown is the count obtained from the area of the sample containing a hole in the middle layer of a three-layer panel. It will be noted that this count is well below the count obtained for the normal three-layer panel.

There are two basic problems associated with the application of beta-ray backscattering to the detection of resin-rich or starved areas in preimpregnated glass layups or molding compounds. These are:

(1) The resin portion of the composite system usually contains a filler to improve flow characteristics during molding. The filler may be any one of a number of materials ranging from talc to aluminum hydroxide, and may be present in quantities of 20 to 30 per cent by volume. In general, the type of filler used is not known by the user. The presence of the third constituent in an appreciable quantity can significantly alter the relation between the number of backscattered electrons and the resin-to-glass ratio.

(2) In mat-molding compound layups, molding compound can replace missing mat layers. When this occurs, it is difficult, if not impossible, to detect the missing mat.

A - Illustrations (16)

B - Bibliography

C - Distribution

ILLUSTRATIONS

ILLUSTRATIONS - Continued

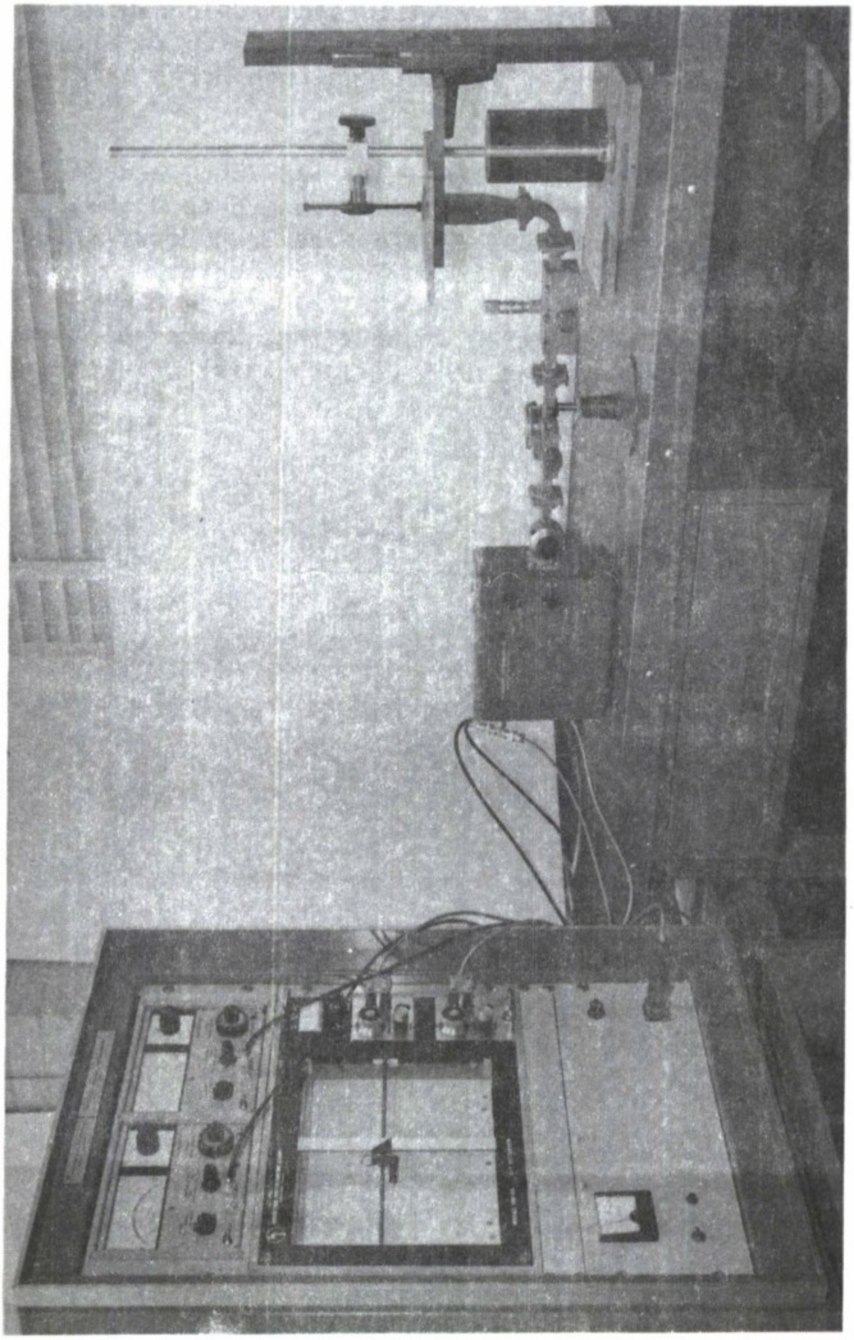

Figure 1. Photograph of Microwave Test Instrument.

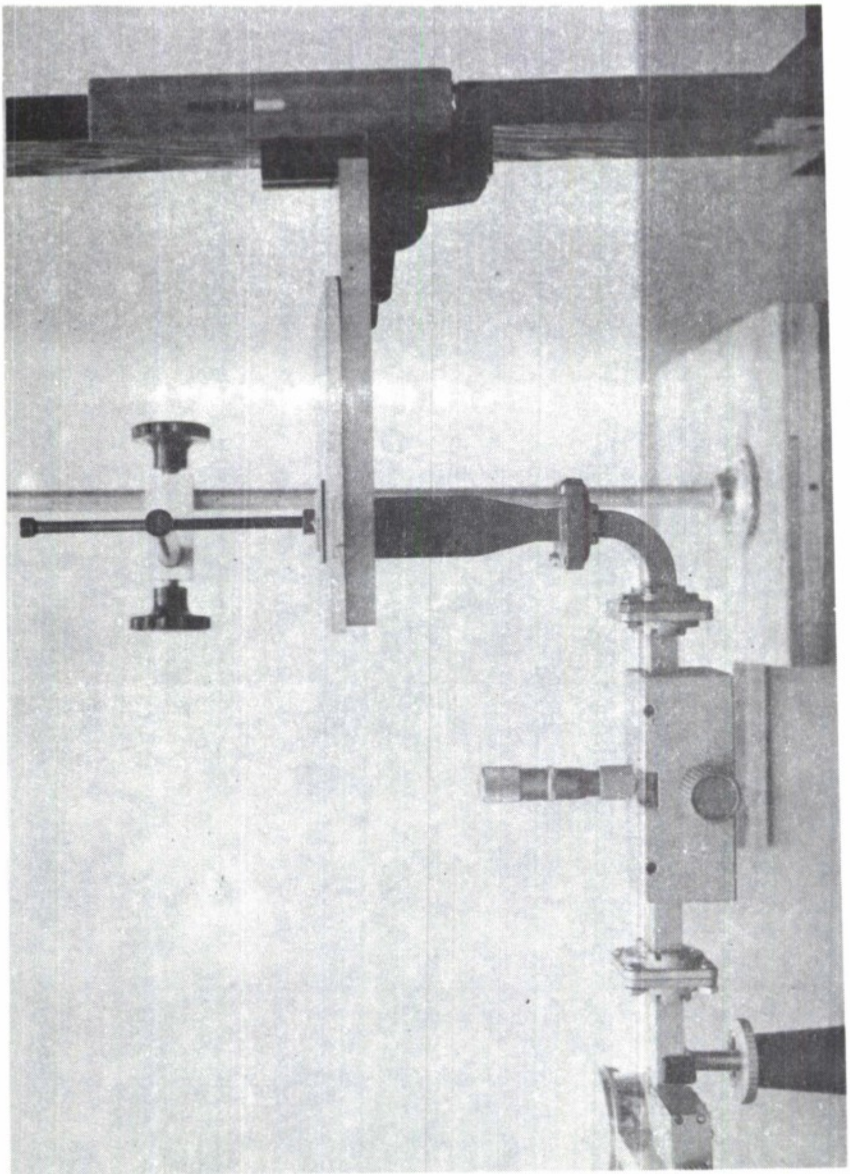

Figure 2. Photograph of the One-Inch Horn, Sample Support, Sample, and Reflector.

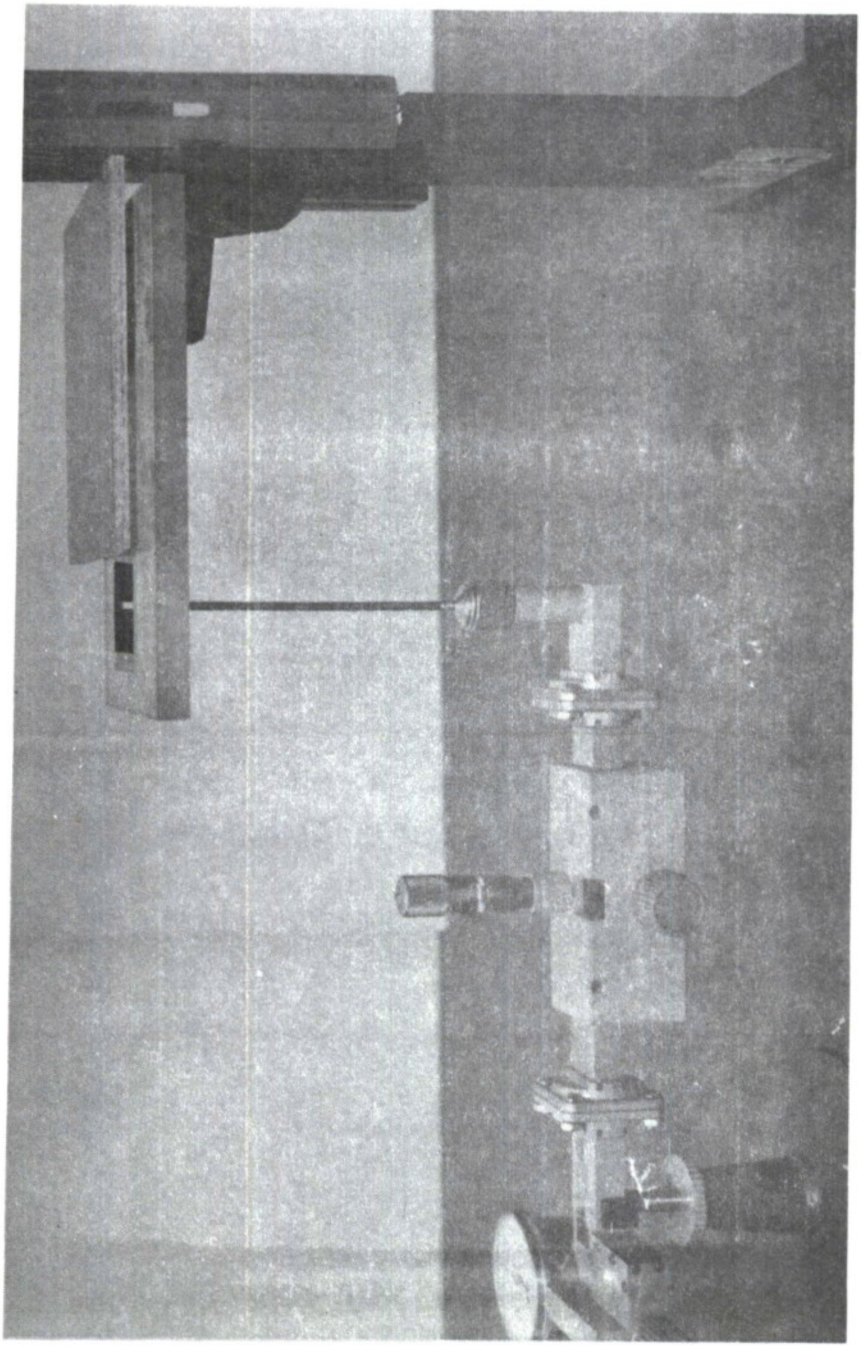

Figure 3. Photograph of the Dipole Probe and Sample.

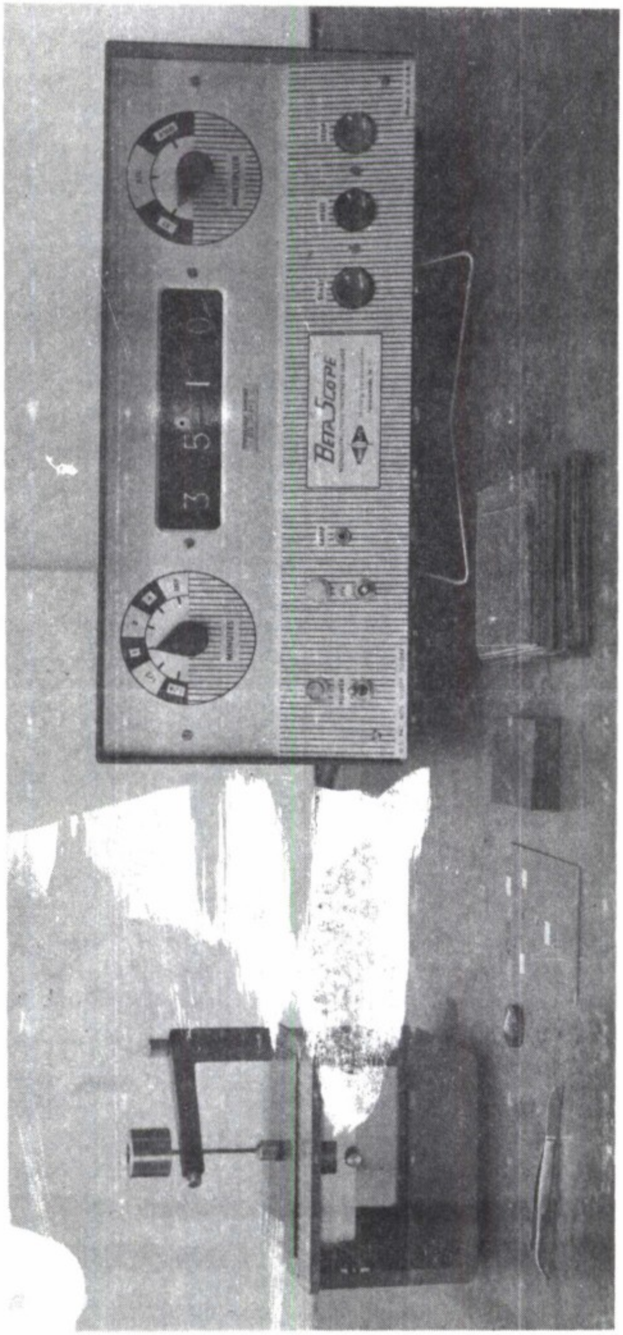

Figure 4. Photograph of Beta-ray Backscatter Instrument.

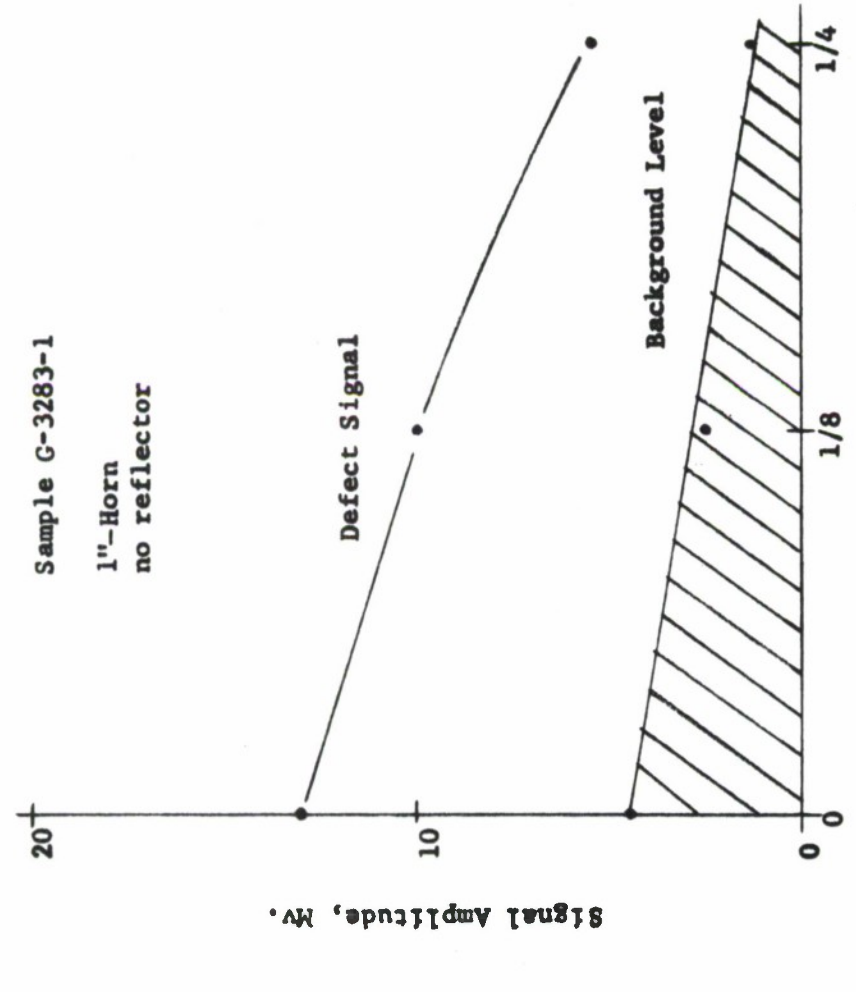

Figure 5. Defect Signal from a 1/4"-Diameter Hole in a 1/4"-Thick Panel of GRP and Background Variability of Sample Versus Separation Between Horn and Sample.

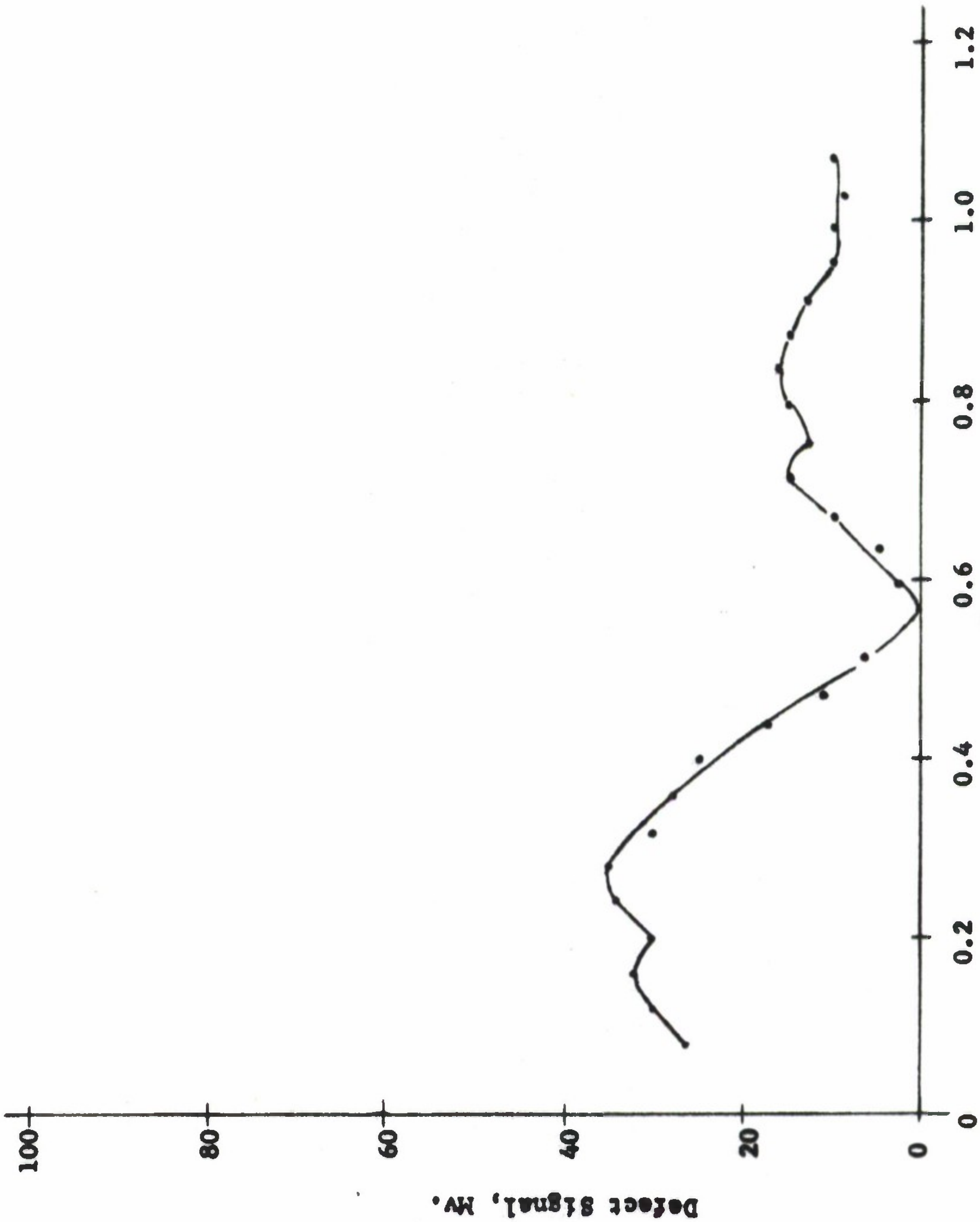

Figure 6. Defect Signal from a 1/4"-Diameter Hole in a 1/16"-Thick GRP Panel versus Reflector Lift-Off.

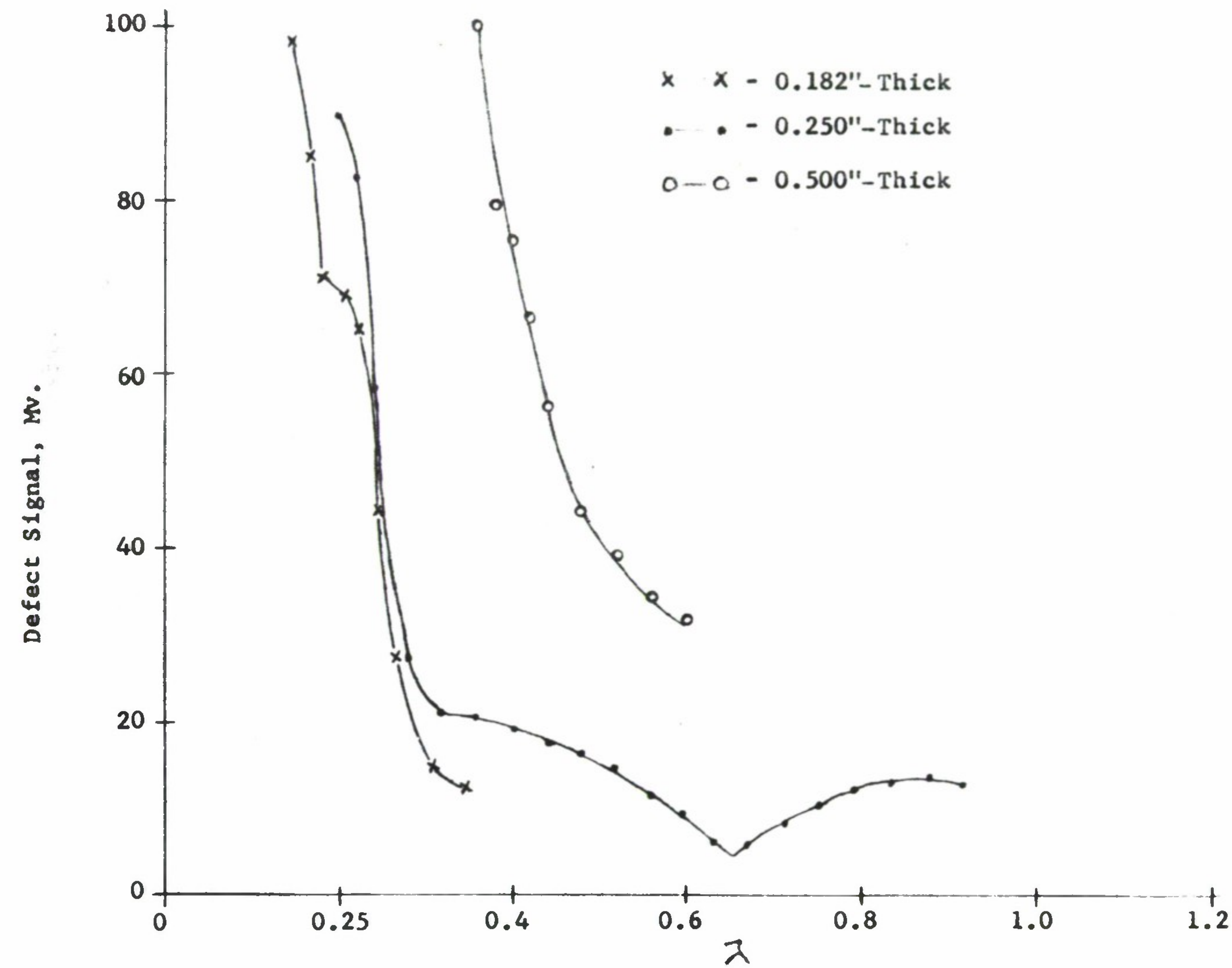

Figure 7. Defect Signal from a 1/4"-Diameter Hole in 0.182", 0.250" and 0.500"-Thick GRP Panels Versus Reflector Lift-Off.

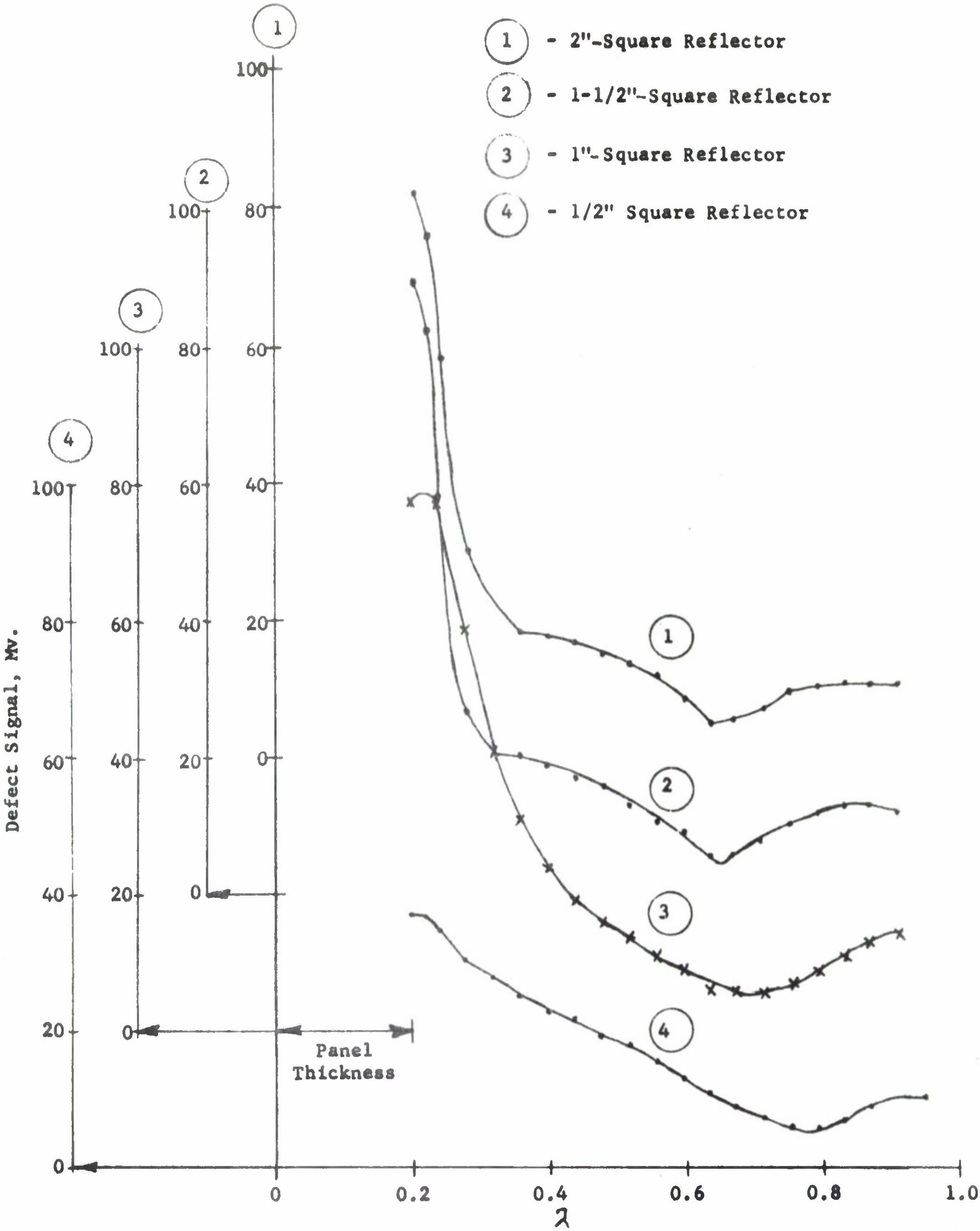

Figure 8. Defect Signal from a 1/4"-Diameter Hole in 1/4"-Thick GRP Panel Versus Reflector Lift-Off for 1/2", 1", 1-1/2", and 2"-Square Reflectors.

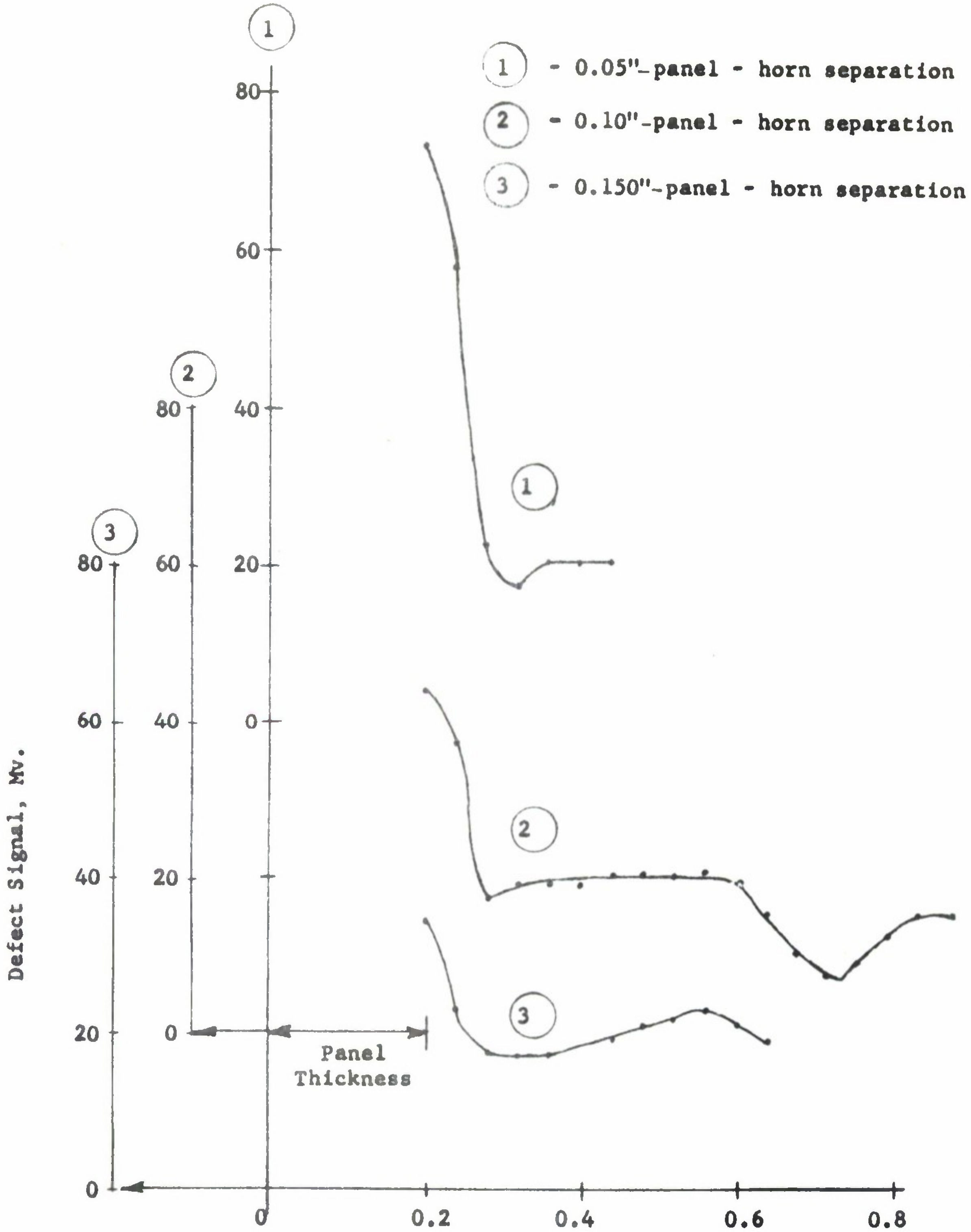

Figure 9. Defect Signal from a 1/4"-Diameter Hole in a 1/4"-Thick GRP Panel Versus Reflector Lift-Off for 0.05", 0.10" and 0.15" Separation Between Horn and Panel.

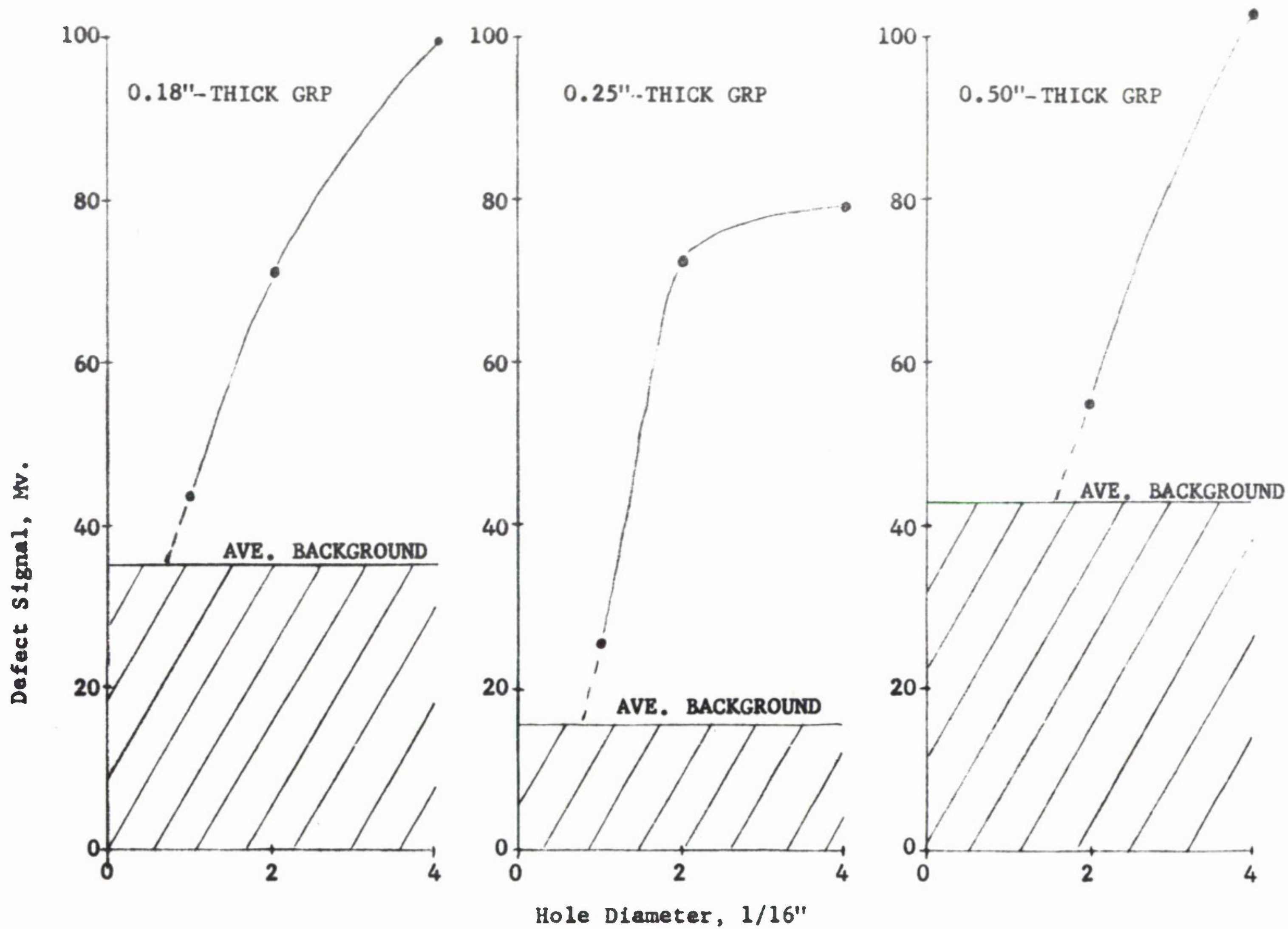

Figure 10. Defect Signal from Through-Drilled Holes, 1/4", 1/8", and 1/16"-Diameter in 0.18", 0.25", and 0.50"-Thick GRP Panels, 1" Horn with a 1-1/2"-Square Reflector.

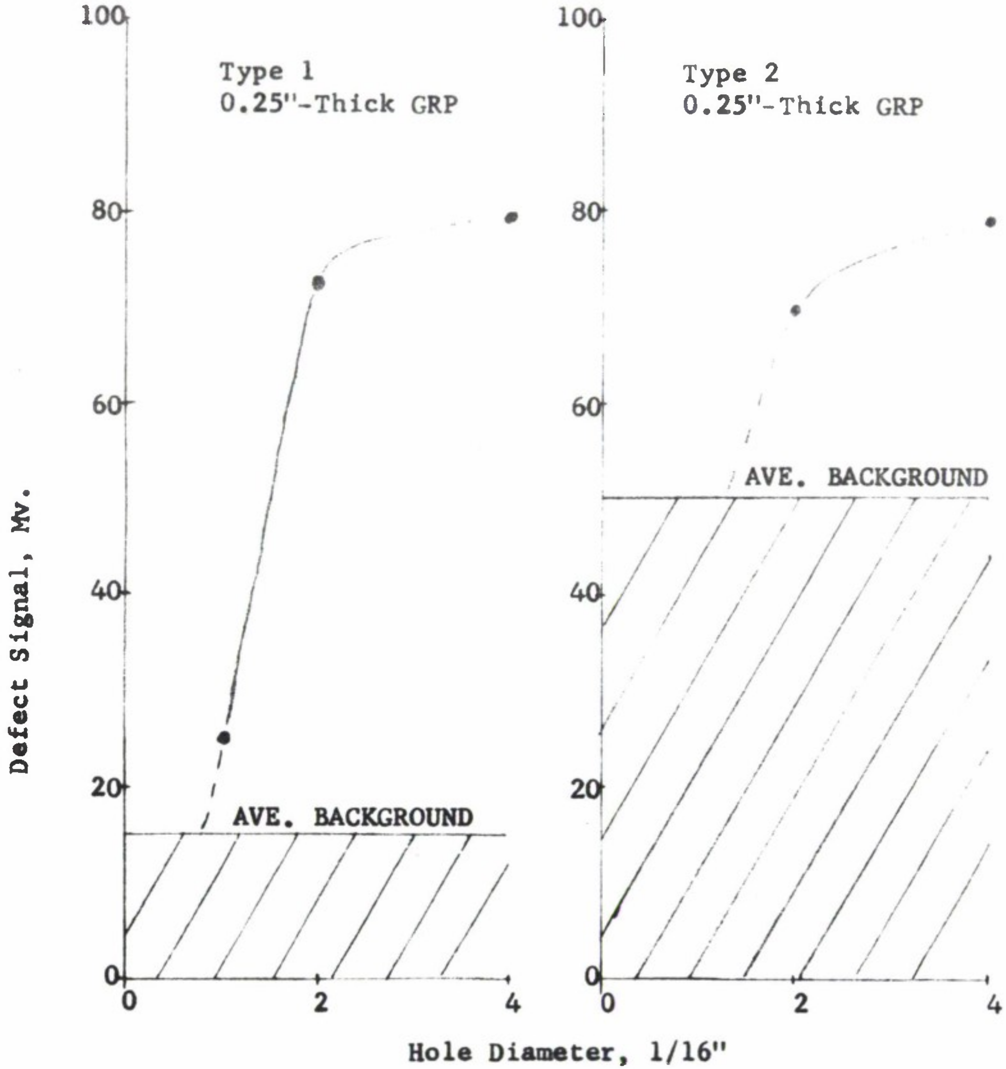

Figure 11. Comparison of Defect Signals from Holes in Two Types of 0.25"-Thick GRP Panels.

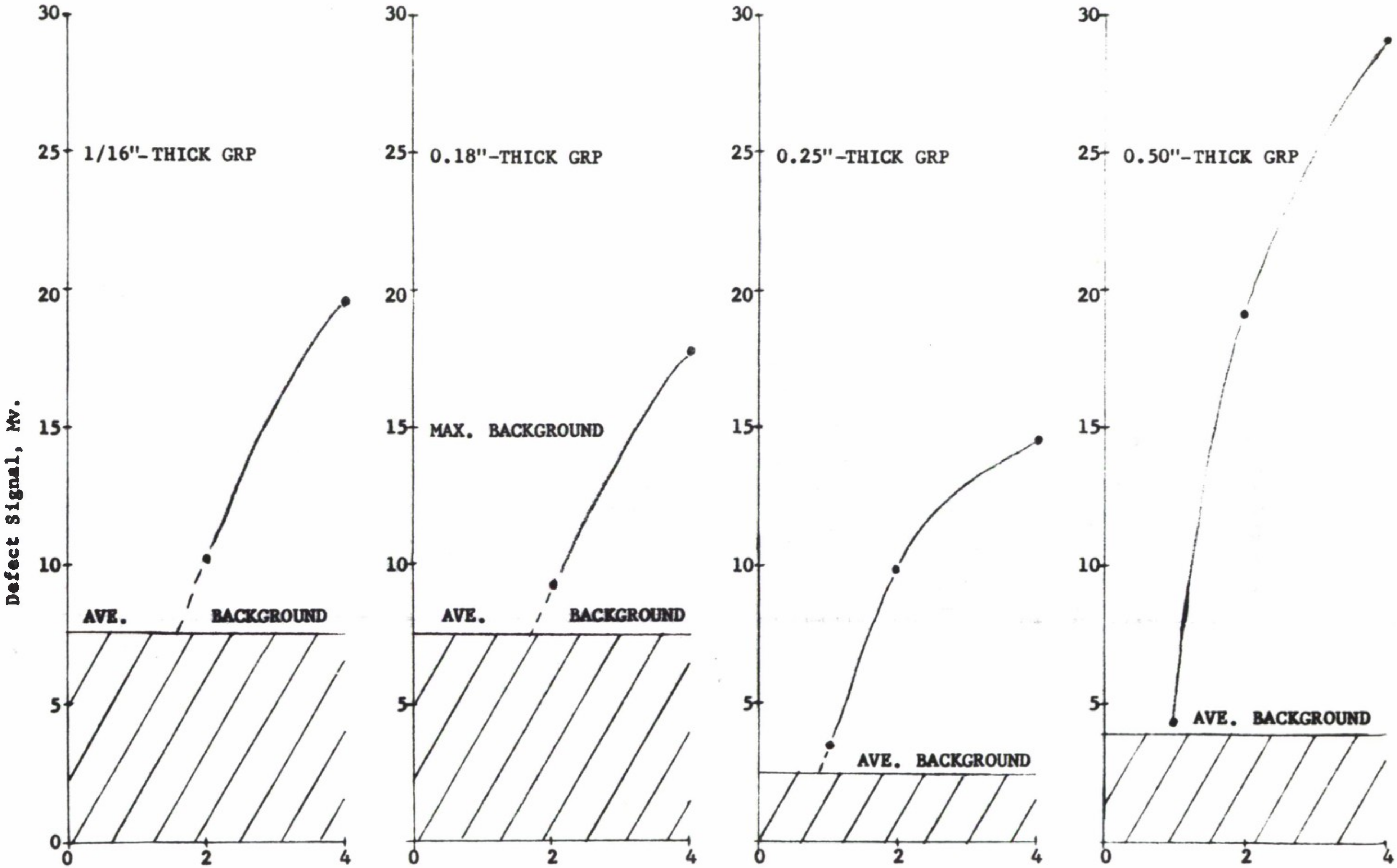

Figure 12. Defect Signal From Through-Drilled Holes, 1/4", 1/8", and 1/16" — Diameter in GRP Panels of Various Thicknesses Obtained Using the Dipole Probe.

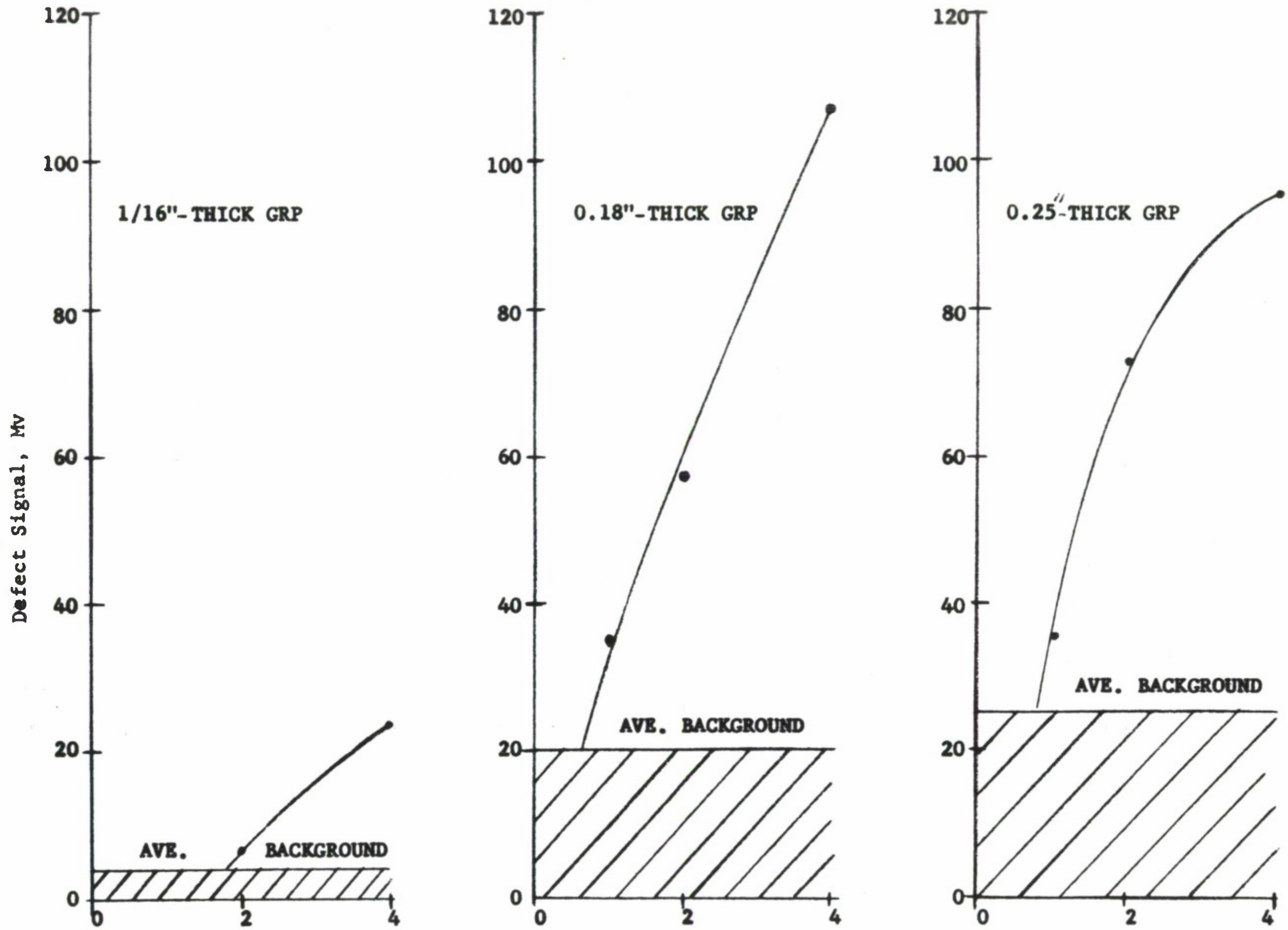

Figure 13. Defect Signal from Through-Drilled Holes, 1/4", 1/8", and 1/16" — Diameter in GRP Panels of Various Thicknesses Obtained Using the 1" Horn with a 9/16"-Diameter Aperture.

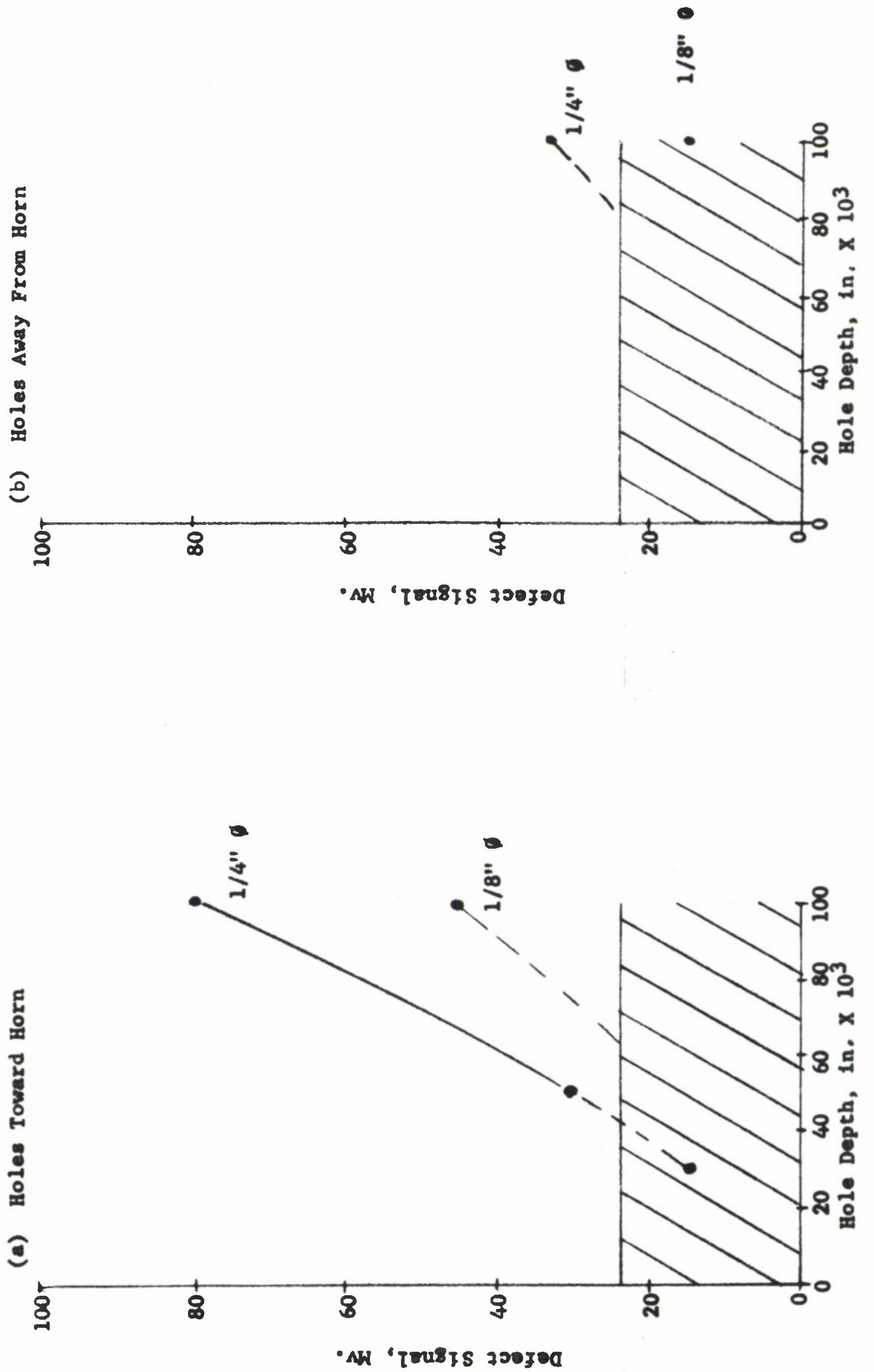

Figure 14. Defect Signal from 1/4" and 1/8"-Diameter Flat-Bottom Holes Drilled to Depths up to 0.10" in 0.25"-Thick GRP Panels, 1" Horn, 1-1/2"-Reflector.

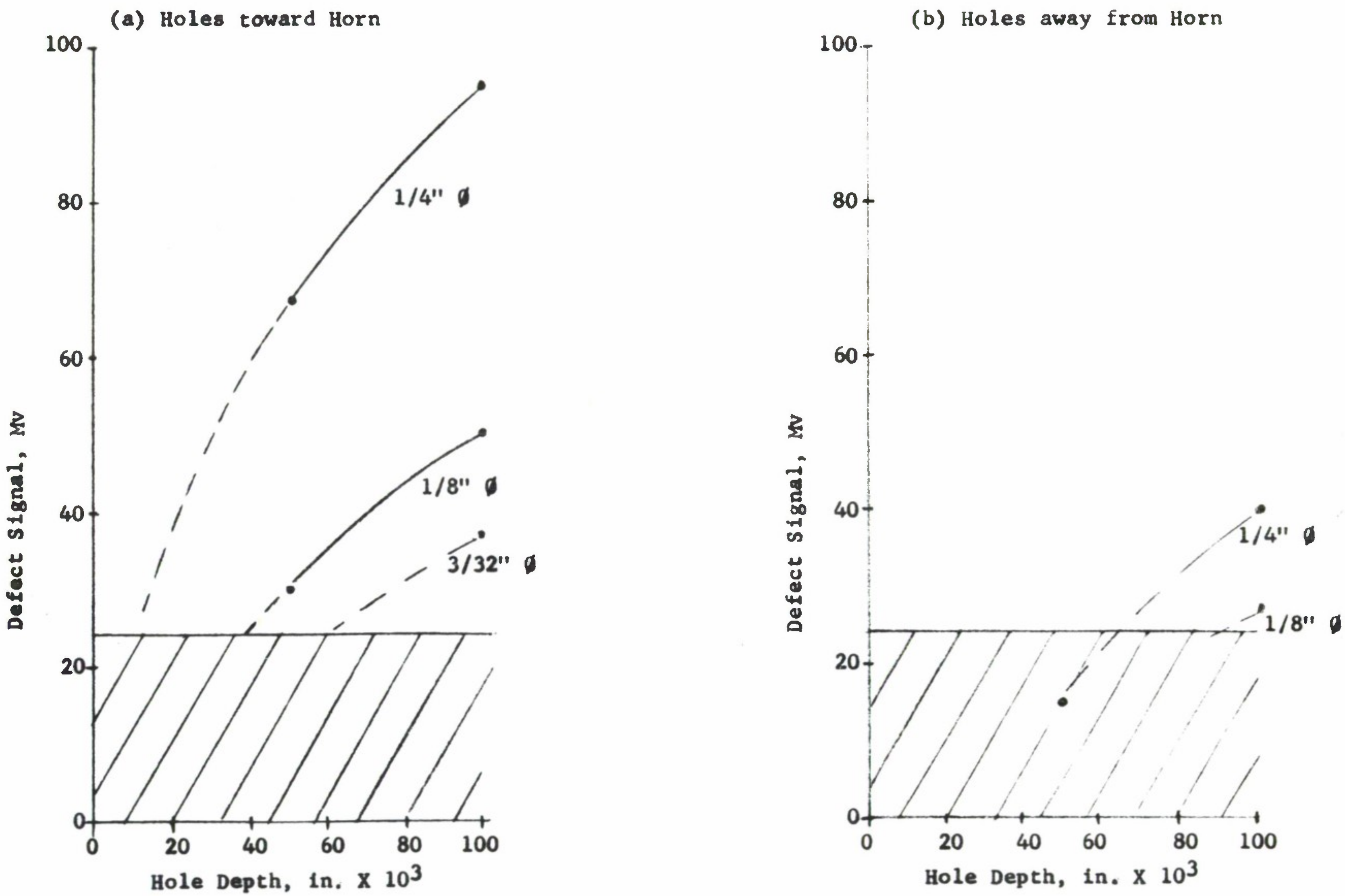

Figure 15. Defect Signal from 1/4", 1/8", and 3/32"-Diameter Flat-Bottom Holes Drilled to Depths up to 0.10" in 0.25"-Thick GRP Panels, 1" Horn, 9/16"-Diameter Aperture, 1-1/2" Reflector.

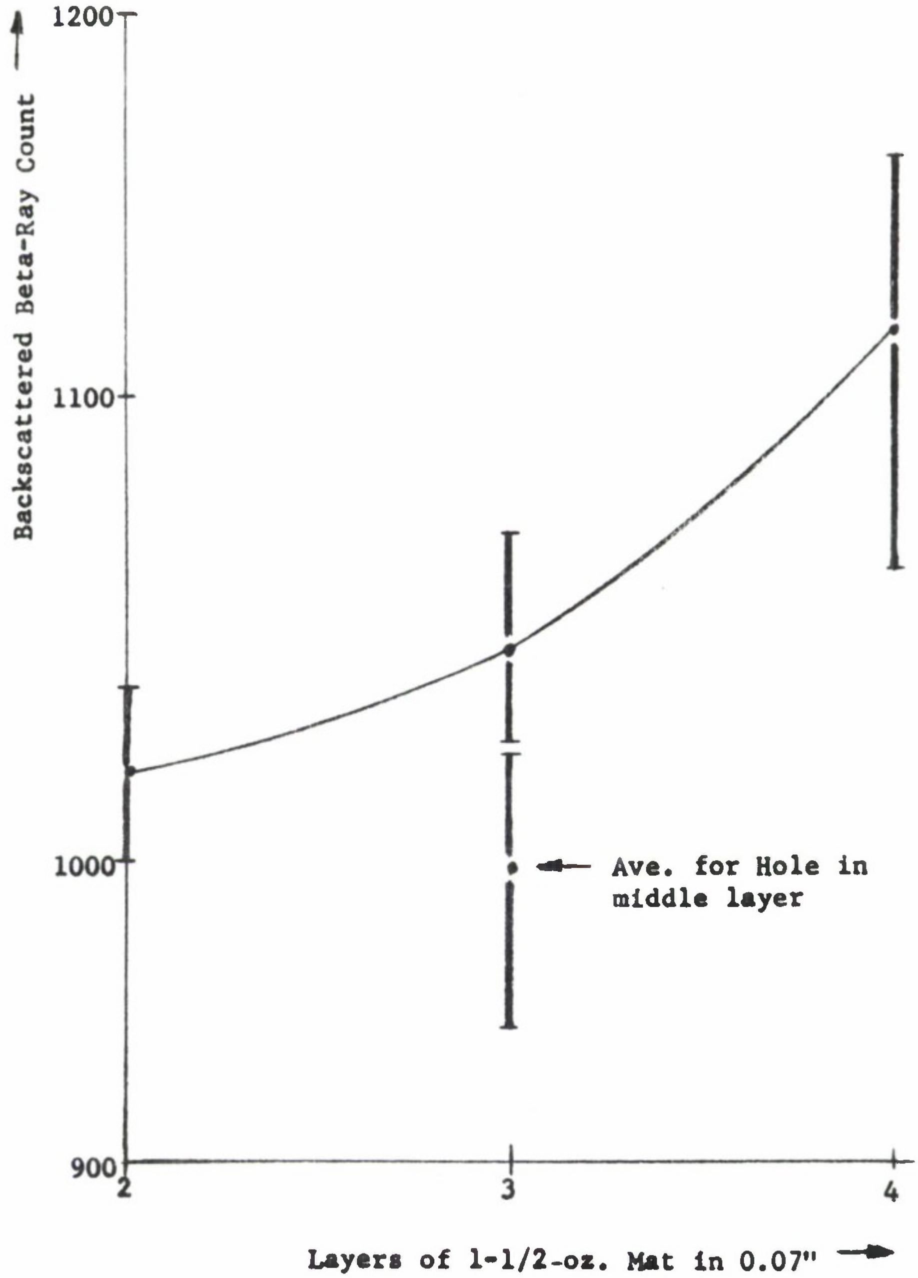

Figure 16. Beta-Ray Backscatter Count Versus Number of Layers of 1-1/2-oz. Mat in 0.07"-Thick GRP Panels. 1.17 Mev. Beta.

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Microwaves were used as a means of detecting voids and inhomogeneities in fiber glass reinforced plastics. A number of experiments that were designed to empirically establish the limits of detectability of various types of defects are described. Based on the results of the investigation, it is possible to detect a 1/8-inch-diameter hole in a 1/4-inch-thick panel of fiber glass reinforced plastic with X-band microwaves. However, several factors such as sensitivity of the signal amplitude to defect location, test-piece position, geometry, and homogeneity make interpretation of results difficult. Beta-ray backscatter measurements are potentially useful as a means of detecting local variations in glass-to-resin ratio. The contribution of fillers as a third constituent in the composite system must, however, be considered in establishing a relation between backscattering and glass-to-resin ratios.

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